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Sampling private wells at past homes to estimate arsenic exposure: A methodologic study in New England

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We are conducting a collaborative, population-based case-control study in Maine, New Hampshire, and Vermont to investigate the reasons for the elevated bladder cancer mortality in northern New England. Arsenic in drinking water is one of the primary exposures under investigation. To estimate subjects' lifetime exposure to waterborne arsenic, it will be necessary to obtain water samples from private wells that subjects used in the past. We conducted a methodologic study to assess the feasibility of locating and sampling from private wells at subjects' past residences. Ninety-eight New Hampshire residents (mean age 67 years) completed a questionnaire requesting the complete address, dates of occupancy, and drinking water sources for each home lived in since birth. An interviewer then asked subjects for more detailed information about each home to assist in a field search of past homes in the three-state study area of Maine, New Hampshire, and Vermont. Fifty-eight of the 98 subjects indicated that they had used a total of 103 private wells in 95 previous homes located in these three states. We conducted a field search to locate these 95 homes, visited town offices to find the properties on tax maps and obtain the current owners' names and addresses, attempted to obtain permission from the current owners to sample the wells, and collected water samples. In all, 48 (47%) of the 103 past wells in the study area were sampled successfully. The remaining wells were not sampled because the homes were not located (22%) or had been demolished (2%), permission to sample the wells was not obtained (17%), the wells had been destroyed (7%) or could not be found on the grounds of the residence (3%), or for other reasons (2%). Various approaches for improving the success rates for sampling water from private wells are discussed, as is the use of predictive modeling to impute exposures when sampling is not feasible.
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Introduction

Data from the *Atlas of Cancer Mortality in the United States, 1950–1994* (Devesa et al., 1999) show elevated mortality rates from bladder cancer among both men and women in the northeastern states, particularly in the northern parts of New England. Elevated rates in both genders have persisted for several decades and have become more pronounced over time, suggesting that an environmental exposure or exposures may be responsible for the elevated bladder cancer mortality in this region.

Epidemiologic studies in other countries indicate that ingestion of drinking water with high arsenic levels increases bladder cancer risk (Chen et al., 1985; Wu et al., 1989; Hopenhayn-Rich et al., 1996; Smith et al., 1998; Chiou et al., 2001). Groundwater in the U.S. typically has low arsenic concentrations (≤ 1 μg/l), but moderate to high levels (>10 μg/l) are prevalent in some regions, including parts of New England (Ayotte et al., 1999; Welch et al., 2000). For example, over 10% of private wells tested in a New Hampshire study contained arsenic levels above 10 μg/l, and 2.5% were over 50 μg/l (Karagas et al., 1998). The potential for ingestion of drinking water with elevated arsenic levels is increased for individuals who use private wells because they typically derive water from crystalline bedrock aquifers, which in New England are more likely to have elevated arsenic levels than unconsolidated aquifers often used by public supply systems (Ayotte et al., 1999; Peters et al., 1999). In addition, private wells are not subject to Federal drinking water standards. Over 40% of the population in northern New England uses private wells as the primary drinking water source, which is a greater proportion than in any other region in the U.S. (Solley et al., 1998). Although the prevalence of exposure to elevated

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arsenic levels in drinking water appears to be relatively high in parts of New England, the arsenic concentrations are lower than those associated with bladder cancer in other countries. The effect of ingestion of arsenic on bladder cancer risk at these lower levels is unknown.

The National Cancer Institute (NCI), in collaboration with the Dartmouth Medical School; the State departments of health in Maine, New Hampshire, and Vermont; and the U.S. Geological Survey (USGS), is conducting a population-based case-control study in these three states to determine the reasons for the elevated bladder cancer mortality in New England. One of the main objectives of this study is to examine the relationship between ingestion of arsenic in drinking water and bladder cancer risk. To accomplish this, it will be necessary to estimate lifetime arsenic exposures of study subjects. Because public water utilities are required to monitor arsenic levels in the water they distribute, we will estimate arsenic exposure from ingestion of water from public sources based on historic monitoring data from water companies in each state. However, there is no monitoring requirement for arsenic in private wells, and thus no readily available data with which to estimate arsenic exposures from private well use.

One approach to estimating arsenic exposure from private well water consumption is to obtain water samples from wells used by study subjects throughout their lifetimes. Whereas this is straightforward for currently occupied homes, the feasibility of obtaining water samples from wells at previous homes is unknown. Therefore, we conducted a methodologic study to assess the feasibility of locating and obtaining water samples from private wells that subjects used in the past.

Methods

Study Population

Subjects selected for this methodologic study were not selected based on any connection with bladder cancer, but were participants in an arsenic biomarker reliability substudy described elsewhere (Karagas et al., 2001a). Briefly, subjects were drawn from controls aged 25 to 74 years from a population-based case-control study of non-melanoma skin cancer in New Hampshire. Controls were frequency matched on age and sex to the distribution of skin cancer cases (Karagas et al., 2001b). To be eligible for the biomarker reliability substudy, controls must have been interviewed between 1995 and 1997, have provided biologic and tap water samples, and have indicated that they currently or previously used a private well as a drinking water source. A total of 208 (95%) of the 220 controls interviewed during this period provided both biologic and tap water samples, 133 of whom reported some private well use. Ninety-nine of these 133 controls participated in the biomarker reliability substudy, and 98 (74% of those eligible) also participated in the methodologic study reported here.

Data Collection

Subjects were mailed a self-administered residential history questionnaire requesting the complete address, dates of occupancy, and drinking water source(s) for each home lived in since birth. If a drinking water source was a private well, subjects were asked to identify the type of well (dug well, drilled well, or spring). During a subsequent home visit, an interviewer reviewed the residential history questionnaire with the participant. For homes served by public water, the interviewer asked the subject to identify the name of the utility that supplied water to the home and the section of town in which the home was located. For homes with private wells, the interviewer asked where the road was in relation to intersecting roads, when the house was built, and the style of the house (e.g., colonial, cape, log cabin). Other information provided for homes with private wells was also recorded, including site descriptions (geographic setting, nearby natural or cultural features), directions to the home (spatial relationship to cultural features), siding style/color, attached or associated structures (barn, garage, swimming pool), orientation with respect to road (parallel, perpendicular), and driveway style (circular, U-shaped, straight). For each private well identified, interviewers administered a Water Use Questionnaire asking for detailed information about the well, such as its location on the property and the well depth.

We restricted our study to past residences with private wells in the three-state study area of Maine, New Hampshire, and Vermont. We conducted a field search to attempt to locate and visually identify each home using address and other descriptive information from the interview. To identify the current owner of each home that we found, we visited the town assessor's office to (1) locate the property on a tax map, (2) use the map and lot numbers from the tax map to find the current owner's name, and (3) identify the current owner's legal address. Once the owner's name and address were determined, a letter requesting permission to visit the property to sample the water was mailed. A second letter was sent if there was no response. Follow-up phone calls were made if a phone number was available. When the homeowner was not the occupant, the owner was asked to provide the renter's name and phone number, or he/she contacted the renter to explain that the water would be sampled. A sampling date and time were arranged at the occupant's convenience. If the well was not currently in use, the sample was collected with a disposable submersible bailer according to USGS protocol (Koterba et al., 1995). If the well was currently in use and there was no water filter, the sample was taken from the tap. If a water filter was in use, the sample was taken from an unfiltered outside tap or an unfiltered tap on the water-system pressure tank. A previously established sampling protocol (Karagas et al., 1998) using a commercially washed (mineral-free) polyethylene bottle was followed. Global positioning system measurements were taken at the location of each sampled well.

Results

The 98 people in the study included 55 men and 43 women. Their cumulative lifetime years at the time of the interview were 6580 and their average age was 67.1 years. Participants provided information about where they lived for 97.7% of their lifetime years. The remaining 151 years were unaccounted for; i.e., the years were completely omitted from the residential histories, or subjects recorded the years but provided no information about where they lived.

The subjects reported 107 current residences (including seasonal homes) and 717 past residences (including military bases and ships, schools, and other institutions). Subjects had been in their current homes for a cumulative total of 2099 years (32% of their lifetimes). All but seven of the current homes were in the three-state area; those outside the study area were seasonal homes, mostly in Florida. Private wells were used at 60% of the current residences, public supplies at 44%, and bottled water at 13% (the number of drinking water supplies exceeds the number of homes because some residences had more than one type of supply) (Table 1). The prevalence of private well use in current homes (60%) was higher than the 40% prevalence reported for New England (Solley et al., 1998) because subjects were eligible for the methodologic study only if they had ever used a private well as a drinking water source.

At the 717 past residences, private wells were used at 20% of the homes, public supplies at 75%, bottled water at 0.4%, other sources at 0.7%, and the water source was unknown at 6%. Of 145 past residences served by private wells, 95 (66%) were in the three-state study area; 30 (21%) were in the nearby states of Massachusetts, Connecticut, and New York; and the other 20 (14%) were in other states or countries.

Table 1. Drinking water supplies in current and past residences.[a]

Type of drinking water supply[b]	Number of residences	
	107 current homes	717 past homes
Public water supply	47 (44%)	535 (75%)
Private well	64 (60%)	145 (20%)
Bottled water	14 (13%)	3 (<1%)
Other	0	5 (<1%)
Unknown	0	44 (6%)

[a]Based on information obtained from interviews with all 98 subjects.
[b]The number of drinking water supplies exceeds the number of homes because some residences had more than one type of supply.

Table 2. Past residences with private wells in Maine, New Hampshire, and Vermont by locatabilty and completeness of address information.[a]

	House number, street, and town	Street and town only	Town only	Total
Residence located	25 (86%)	43 (81%)	7 (54%)	75 (79%)
Residence not located	4 (14%)	10 (19%)	6 (46%)	20 (21%)
Total	29 (100%)	53 (100%)	13 (100%)	95 (100%)

[a]Based on information obtained from interviews of 58 subjects with past homes with private wells in the three states.

Locating and Sampling Past Homes With Private Wells

We attempted to locate the 95 past residences with private wells in the three-state study area. These 95 homes had been identified by 58 subjects (the remaining subjects had wells only in their current homes, or had past wells only at homes located outside of the study area). A total of 809 person-years were spent in these homes, and the homes had a total of 103 wells.

Subjects provided complete addresses for 29 (31%) of the 95 past residences of interest (Table 2). Street and town names (but not house numbers) were given for 56% of these homes, and only town names were provided for 14%. Overall, 79% of the residences were located in the field search (including two homes that had been demolished but whose properties were found); these residences represented 73% of the person-years spent in the 95 homes.

Our success in locating homes was related to the completeness and accuracy of the addresses and to the types of descriptive information provided by the subjects. About 54% of the homes with only town name were located; this increased to over 80% when more complete address information was given (Table 2). We could not locate some homes with complete addresses because the house number was reported incorrectly, the street name was apparently assigned to the wrong town, or the street name or house number had changed since the subject moved out. On the other hand, over half of the homes with neither house numbers nor street names were located because subjects gave detailed descriptive information about the home and its location. If enough information was provided to guide us to the approximate location of the home (e.g., a nearby street or intersection name, or a landmark), and if the description of the home was sufficiently detailed to distinguish it from others in the area (e.g., style, approximate year home was built, type of driveway, location relative to other homes on the street), we were able to locate the home despite the lack of address information.

Our ability to locate homes was related somewhat to the subject's gender and age at interview. We successfully located 83% of the residences identified by men, compared to 76% for women. Of the 42 homes identified by subjects who were under age 65 at interview, 43% had complete

Table 3. Past residences with wells in Maine, New Hampshire, and Vermont by ability to sample water.

	Number (%) of homes	Number (%) of wells at homes
Total	95 (100%)	103 (100%)
Home located	75 (79%)	80 (78%)
Permission to sample well(s) obtained	55 (58%)	60 (58%)
Well(s) sampled	44 (46%)	48 (47%)

addresses and 86% were located. Of the 53 homes identified by older subjects, only 21% had complete addresses, but 74% were located.

With the exception of the two homes that had been demolished, we were able to identify the current owners of all of the located homes. We sent letters to the 73 current owners requesting permission to sample the water. Permission was obtained from 55 owners (75% of those contacted). The properties of these 55 residences were searched for wells. According to the residential history questionnaires, these 55 homes had a total of 60 wells used as a drinking water source in the past.

Of these 60 wells, 48 (80%) were sampled. The remaining 12 wells were not sampled for the following reasons: seven had been destroyed, three could not be found on the properties of the homes, one was dry, and one was contaminated with discharge from a treatment system being used on another well. Nineteen (40%) of the sampled wells were dug wells, 22 (46%) were drilled, and 7 (15%) were springs.

In summary, 48 wells were sampled at 44 past homes (Table 3). The 48 sampled wells comprise 47% of the 103 past private wells identified by 58 subjects in the three-state study area. We did not sample 23 wells (22%) because the homes could not be located; 2 (2%) because the homes had been demolished; 18 (17%) because we were not given permission to sample; and 12 (12%) because the wells had been destroyed, could not be located on the property, or for other reasons. Overall, the 44 past homes at which wells were sampled represent 46% of the 95 past homes with private wells in the study area, or 41% of the person-years in these homes.

Our success in locating homes, obtaining permission to sample the wells, and obtaining a water sample was not related to the number of years the subject lived in the home. However, a strong factor was how recently the subject lived in the home (Table 4). All of the homes that subjects vacated in 1990 or later were located, and water samples were obtained from all but one of them. The probability of obtaining a water sample was much lower for homes that subjects vacated prior to 1990 (typically 50% or less). At many of the homes that subjects vacated prior to 1960, the wells had been destroyed or could not be found on the property.

Sampling of the 48 wells provided the opportunity to examine the accuracy of information on well type reported by subjects in their residential history questionnaires. Subjects reported well type correctly for 42 wells (88%). For three wells, the type was originally reported as unknown (two were subsequently found to be dug wells and one was a drilled well). Three wells were reported incorrectly: two drilled wells were reported as dug wells, and one dug well was reported as a drilled well. Subjects always reported wells fed by springs accurately (N=7).

Identifying Public Water Utilities at Past Homes

Of 535 past residences served by public water (Table 1), 169 (32%) were in the three-state study area; 206 (39%) were in the nearby states of Massachusetts, Connecticut, and New York; and 160 (30%) were in other states or countries. Of the 169 residences in the three-state study area, subjects provided the name of the utility that supplied water to 43 (25%). We compared the utility names with the U.S. Environmental Protection Agency's list of current community (nontransient and transient) water supplies and found 41 of the 43 utilities on the list (U.S. Environmental Protection Agency, 2001).

Discussion

Studying the chronic health effects from ingestion of arsenic in drinking water requires an estimate of lifetime arsenic exposures of study subjects. In New Hampshire, exposure

Table 4. Past residences with private wells in Maine, New Hampshire, and Vermont by year moved out and ability to sample water.

Year moved out of home	Total no. of homes	No. (%) of homes located	No. (%) of homes with permission to sample well(s)	No. (%) of homes with well sample(s) taken
≥1990	12	12 (100%)	11 (92%)	11 (92%)
1980–1989	10	9 (90%)	5 (50%)	5 (50%)
1970–1979	15	10 (67%)	7 (47%)	7 (47%)
1960–1969	15	15 (100%)	10 (67%)	8 (53%)
1950–1959	26	17 (65%)	12 (46%)	6 (23%)
<1950	17	12 (71%)	10 (59%)	7 (41%)
Total	95	75 (79%)	55 (58%)	44 (46%)

assessment at a subject's current home will cover only about one-third of the subject's lifetime. The ability to estimate exposures at previous homes is particularly important for etiologic studies of cancer, where there is often a long latency period between exposure and disease.

Through the methods employed in this study, we successfully obtained water samples from 47% of the wells at past homes in the three New England states. We have identified strategies that could increase this success rate. First, interviewers should systematically probe for detailed information about the home (e.g., age, style, type/color of siding, attached structures, driveway style), the presence of nearby landmarks (e.g., schools, churches, hospitals, parks), the names of intersecting streets, and, if time allows, directions to the home. This should be done even when complete addresses are given because street names and house numbers change over time, subjects sometimes err, and in rural locations the mailing address is often nonspecific, such as rural free delivery (RFD) routes or post office boxes.

Second, it is important to obtain permission to recontact a subject if a small amount of additional information is needed to locate a home. We found that six more homes (6%) could have been located had the subject been recontacted toward the end of the field search and asked one additional question.

Third, comments from homeowners provided insight as to why permission to sample the water was denied in some cases. Some homeowners indicated that the introductory letter, which stated that the well-sampling effort was part of a groundwater quality study in northern New England, did not adequately explain how their home was chosen or how we knew about the presence of wells that are no longer in use. A more complete rationale needs to be included in the introductory letter. In addition, the introductory letter stated that the sampling process would take up to 1/2 day. When sampling techniques were subsequently refined to shorten the time to less than 15 min, some homeowners reversed their initial decision to deny permission. Finally, offering to send the homeowners the results of the laboratory testing of the water sample should be an incentive for some homeowners to grant permission.

Further, to improve the estimation of lifetime arsenic exposures in New England, it is necessary to expand the field search of past homes beyond Maine, New Hampshire, and Vermont. New Hampshire residents identified 145 past homes with private wells in this study, 30 (21%) of which were in the nearby states of Massachusetts, Connecticut, and New York.

Whereas the strategies described above may increase success at locating and sampling water from past residences, well sampling alone may not be sufficient to estimate subjects' exposures to arsenic from private wells in New England. First, difficulties in locating homes and sampling wells are inevitable, particularly at homes that people vacated long ago. Second, using current arsenic measurements to represent concentrations at the time of exposure, which could have been years or decades ago, raises the issue of the variability of arsenic concentrations in groundwater over time. Few studies of the long-term variability of arsenic levels at a single well location have been reported. Karagas et al. (2001a) analyzed two tap water samples taken 3 to 5 years apart from each of 99 homes in New Hampshire served mostly by private wells. Little temporal variation in arsenic concentrations was found. However, data from outside the study area present an uneven picture. Focazio et al. (2000) analyzed the variability in arsenic concentrations over time in 355 wells in the U.S. (time periods unspecified). Arsenic concentrations were temporally stable in 116 wells with very low arsenic levels (<1 μg/l); however, temporal variations that could be significant for exposure assessment were observed in many wells with higher arsenic levels. In a one-year study of 17 wells in Oregon, arsenic concentrations in water from many wells remained essentially constant, but levels at some wells varied by up to almost 50% from mean concentrations (Hinkle and Polette, 1999). These studies did not attempt to determine the causes of the variability in arsenic levels, which could have been due to natural geochemistry, differences in sampling or laboratory methods, or other factors. The extent of temporal variation in arsenic levels and its effect on exposure classification in a cancer epidemiology study in New England are unknown. This will be evaluated in the early stages of the case-control study.

We conclude that development of a predictive model for arsenic concentrations in groundwater supplies is needed to supplement the direct water sampling effort. This model would be used to classify relative exposure potential at wells that cannot be sampled. If temporal variability in arsenic levels is deemed an important factor in New England, we will investigate the feasibility of developing specific models to evaluate the effect of temporal variation on exposure classification.

Developing predictive models for arsenic in groundwater will require compilation of groundwater arsenic data from existing water quality databases in New England. For example, the USGS has analyzed groundwater from randomly located wells in the unconsolidated and bedrock aquifers of New England as part of the National Water-Quality Assessment Program (Ayotte and Robinson, 1997). Groundwater quality data for public supply wells and from regional aquifer studies are also available from state and other federal agencies. Other information pertinent to such a modeling effort includes location of and arsenic concentrations in current and past wells of study subjects, and geologic, hydrologic, and land-use information. Regional-scale relations between arsenic concentrations in groundwater and some of these variables have been found (Ayotte et al., 1999).

It is also important to assess arsenic exposures from public water supplies. Although levels in public supplies are likely to be lower than those in private wells, information collected in our study indicates that public water is an important source of drinking water for the New England population. Arsenic exposures at past homes served by public water can be assessed by obtaining arsenic monitoring data from the water utility that served the home. In our study, subjects provided correct names of water utilities for only about one-fourth of the past homes in the three-state study area. However, past studies have successfully linked water utility monitoring data to residential histories by town name, using state data on the towns served by utilities (Ward et al., 1996; Cantor et al., 1998; Hildesheim et al., 1998). Additional efforts might be needed to identify the correct utility for a residence that is located in a town served by multiple utilities, or to account for variation of contaminant levels within a utility's distribution system (Croen et al., 2001).

Estimation of subjects' lifetime exposure to inorganic arsenic from ingestion of water in New England will require a variety of methods, including sampling water from subjects' current and past private wells, applying modeling techniques to impute exposures, and obtaining historical arsenic monitoring data from public utilities. Although direct sampling of water is believed to be the preferred method of estimating arsenic exposures from private wells used in the past, this method poses numerous logistical problems. Lessons from this methodologic study can be applied to improve the estimation of subjects' exposure to arsenic from ingested water in analytic studies of the health effects of arsenic exposure.

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